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OPERATIONAL TESTS OF THE COHERENT OPTICAL FINGERPRINT IDENTIFICATION SYSTEM (COFIDS)

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13. ABSTRACT

At the request of the U. S. Army Office of the Provost Marshal General, the U. S. Army Land Warfare Laboratory performed a test and evaluation of the Coherent Optical Fingerprint Identification System (COFIDS). This system employs the techniques of optical holography to encode fingerprint details and store such information, with high data density, on miniature photographic films. Identification is performed by comparing fingerprints with the hologram using optical cross-correlation. The test, involving over 100 people of USALWL, was carefully designed and instrumented to provide complete statistics of performance. The evaluation indicates that the system provides a highly foolproof means of personnel identification. Equipment improvements are desirable to automatically compensate for fingerprint variability and to reduce the learning process required of users.

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INTRODUCTION

At present, the primary means for controlling access to "controlled security" areas is the use of photo-identification cards and guard personnel. Instances of the failure of this method are legend. It has been obvious for a long time that some automatic identification system is needed to eliminate human error and counterfeiting of identification cards.

The KMS Technology Center developed such an automatic identifier with the support of the DOD Advanced Research Projects Agency (ARPA). This system, known as the Coherent Optical Fingerprint Identification System (COFIDS), uses the techniques of modern holography to compare a person's fingerprint in real-time with a hologram of his print permanently attached to an identification card. The uniqueness of fingerprints, the virtually unbreakable codes provided by the hologram, and the elimination of humans from the identification process lead to a potentially very-high level of security.

At the request of the U. S. Army Office of the Provost Marshal General, the U. S. Army Land Warfare Laboratory tested several of the prototype COFID systems during July-August 1971. Unfortunately, the prototypes had been subjected to extensive development testing and modification. As a result, the systems were highly unreliable during the tests and displayed widely different characteristics. The tests indicated that the technique had promise but could not establish true performance levels.

In January 1972, KMS Industries, Inc. provided new production models of the COFIDS for further testing of the system. A test was conducted during January-February 1972. This report covers the results of that test.

DESCRIPTION OF EQUIPMENT

The COFID system includes two types of optical devices, the master and slave correlator units. The system utilizes one master unit and one or more slave units.

The master unit, Figure 1, is required to prepare ID cards. It contains a helium/neon gas laser and associated optical components to generate a hologram of a fingerprint. The hologram is recorded on a small disc of photographic film contained in the ID card.

The slave correlator is similar in appearance and size to the master unit, Figure 2. The slave units can correlate fingerprints with previously prepared ID cards but they cannot generate new ID cards. Correlation is provided by use of a coherent light source (a helium/neon laser like that of the master unit) and an associated optical system which perform matched filter cross-correlation between the fingerprint and the ID card. The output of this process is a beam of light, the peak intensity of which varies with the degree of correlation. This light is converted into an

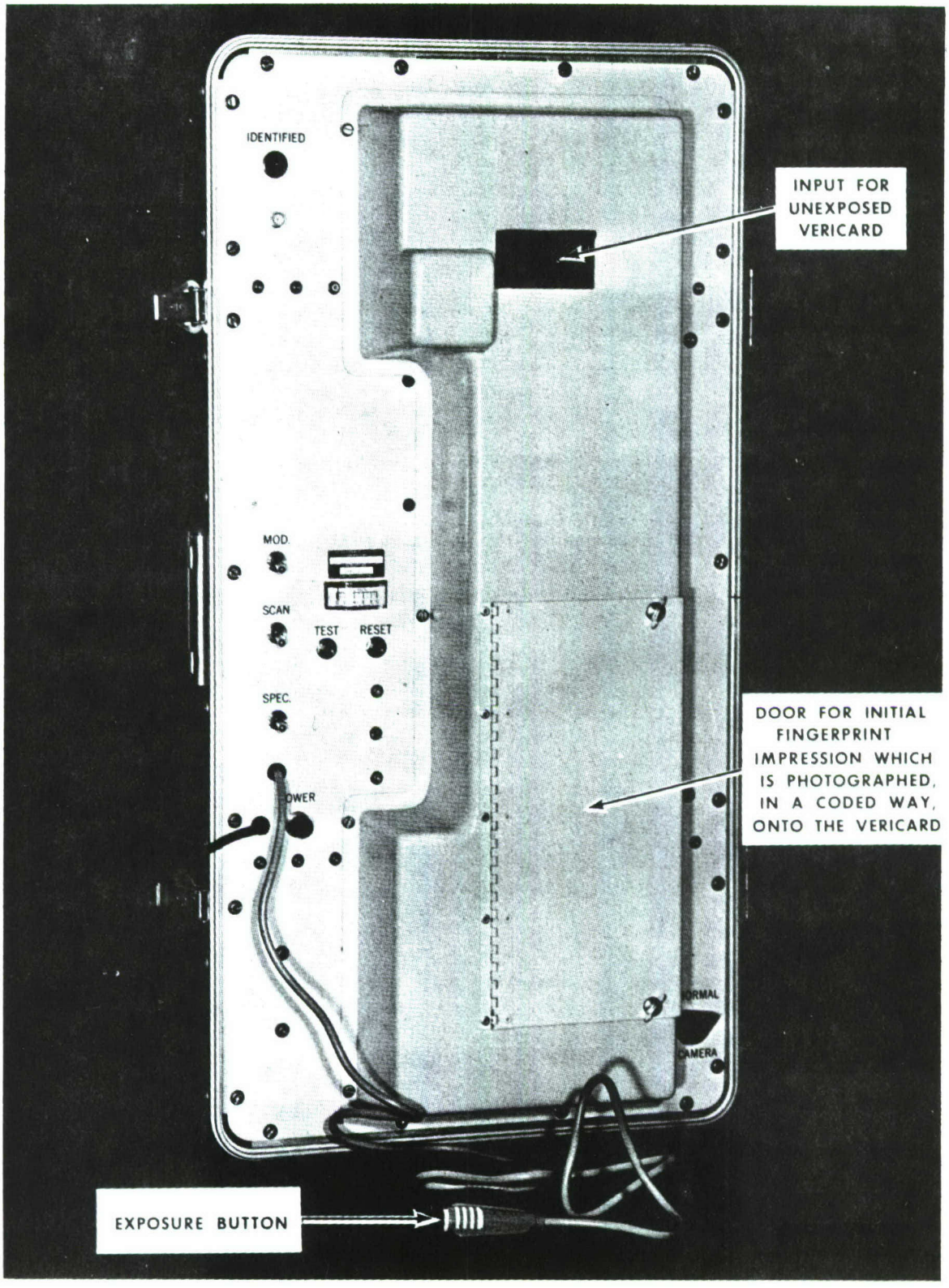

FIGURE 1: COFIDS Master Correlation Unit

FIGURE 2: COFIDS Slave Correlation Unit

electrical signal by a photocell, amplified, and compared with an adjustable threshold voltage. Correlation is recognized by the slave unit when the comparison signal exceeds the threshold setting.

Both the master and slave units are approximately 16" Wide X 30" H x 10" deep. The master unit weighs approximately 90 lbs. The slave units tested weigh approximately 60 lbs each. The equipment requires 110 volts, 60 Hertz power.

The identification cards are simple 2-1/8" x 3-3/8" plastic plates similar to standard credit cards. Each card has three holes punched through it. Two of the holes (3/16" in diameter) are used to register, accurately, the card in the COFID units. The third hole (approximately 1/8" in diameter) contains the photographic negative on which the fingerprint hologram is recorded.

TEST PROCEDURE

The test involved 106 employees of the USALWL. Initially, identification cards were produced for each of the participants. Then each participant was instructed to make four appearances at the COFID unit each day. At each appearance, he was required to make four attempts at verification: three of the attempts with his own card and one attempt with the card of another person. The three attempts with his own card provided a measure of true-correlation rate between a person's fingerprint and his card. The fourth attempt with another person's card provided a measure of the rate of false correlation. The card used for false correlations was changed twice a day throughout the four-week test period.

Two COFID units were used in the test, one in each of two buildings of the USALWL. Although the employees in each building tended to use the COFID unit in that building most of the time, there were no restrictions placed on usage and considerable "crossover" between buildings occurred. A summary of the statistics of participation is given in Table 1.

Both the occurrence of correlation and the degree of correlation were measured. A go no-go light on the COFID units indicated correlation. A chart recorder monitoring an internal COFID waveform provided a record of the degree of correlation (voltage) for each attempt.

To a great degree, the test participation was voluntary. Neither failure to participate fully nor failure to obtain correlation at an appearance resulted in any penalties on the participant. Unlike an actual security situation, where failure to correlate would bar entry to the controlled area, the participants were not motivated realistically. The test provided no means for measuring this factor quantitatively. However, it is anticipated that in a realistic security situation, where personnel are motivated to obtain correlations, the performance of the system would be better than it was in the USALWL test situation.

TABLE 1

STATISTICS OF COFIDS TEST

Total Number of Personnel Participating - 106

Test Period Appearances

January 1972				February 1972															
26	27	28	31	1	2	3	4	7	8	9	10	11	14	15	16	17	18	22	23	24	25

Unit 1

			41	33	24	25	29	28	25	27	39	32	33	34	48	47	37	37	38	41	44

Unit 2

34	137	107	133	89	65	99	92	94	126	105	92	32	119	129	127	118	127	123	124	104	121

Totals

Unit Number	Total Number of Appearances	Total Number of True-Correlation Attempts	Total Number of False-Correlation Attempts
1	662	1,986	662
2	2,297	6,891	2,297

The test was designed to measure system capabilities in terms of the following criteria:

1. Capability of producing satisfactory identification cards.

2. Ability of participants to obtain true correlation within a reasonable number of attempts, given a good identification card. (For the purposes of this test, a reasonable number of attempts to obtain identification is taken as three; however, in practice, a "reasonable" number of attempts depends upon the application.)

3. Ability of the COFIDS to reject unmatched combinations of ID cards and fingerprints (low false-correlation rate).

4. Performance differences between the two COFID units used in this test.

5. Equipment reliability.

TEST RESULTS

1. Identification Cards

The preparation of identification cards employs a special master COFID unit which records a unique hologram of a fingerprint on photographic film mounted in the ID card. Production of ID cards which provide good correlations with fingerprints depends upon the quality of the fingerprint obtained in preparing the card, the adjustment of the master unit, the condition of the film in the card, and the film-processing technique. As a result, the preparation of cards involves some trial-and-error and is greatly dependent upon the experience of the people performing this operation.

On the average, it required 2.5 attempts per person to prepare satisfactory identification cards. All but twelve of the participants required more than one card to be prepared. One participant required seven attempts to prepare a usable card. Another person originally scheduled to participate in the tests had such poorly defined fingerprints that a satisfactory identification card could not be prepared.

2. True-Correlation Performance:

The ability of participants to obtain true correlation is described in Figure 3 (for COFID Unit 1) and Figure 4 (for COFID Unit 2). The graphs indicate the percentage of all appearances during each day of the test which resulted in true correlations. Each figure contains three plots. One plot indicates the percentage of successes attained on the first attempt. The second plot indicates the percentage of successes attained within two tries (1st-try successes and 2nd-try successes combined). The third plot

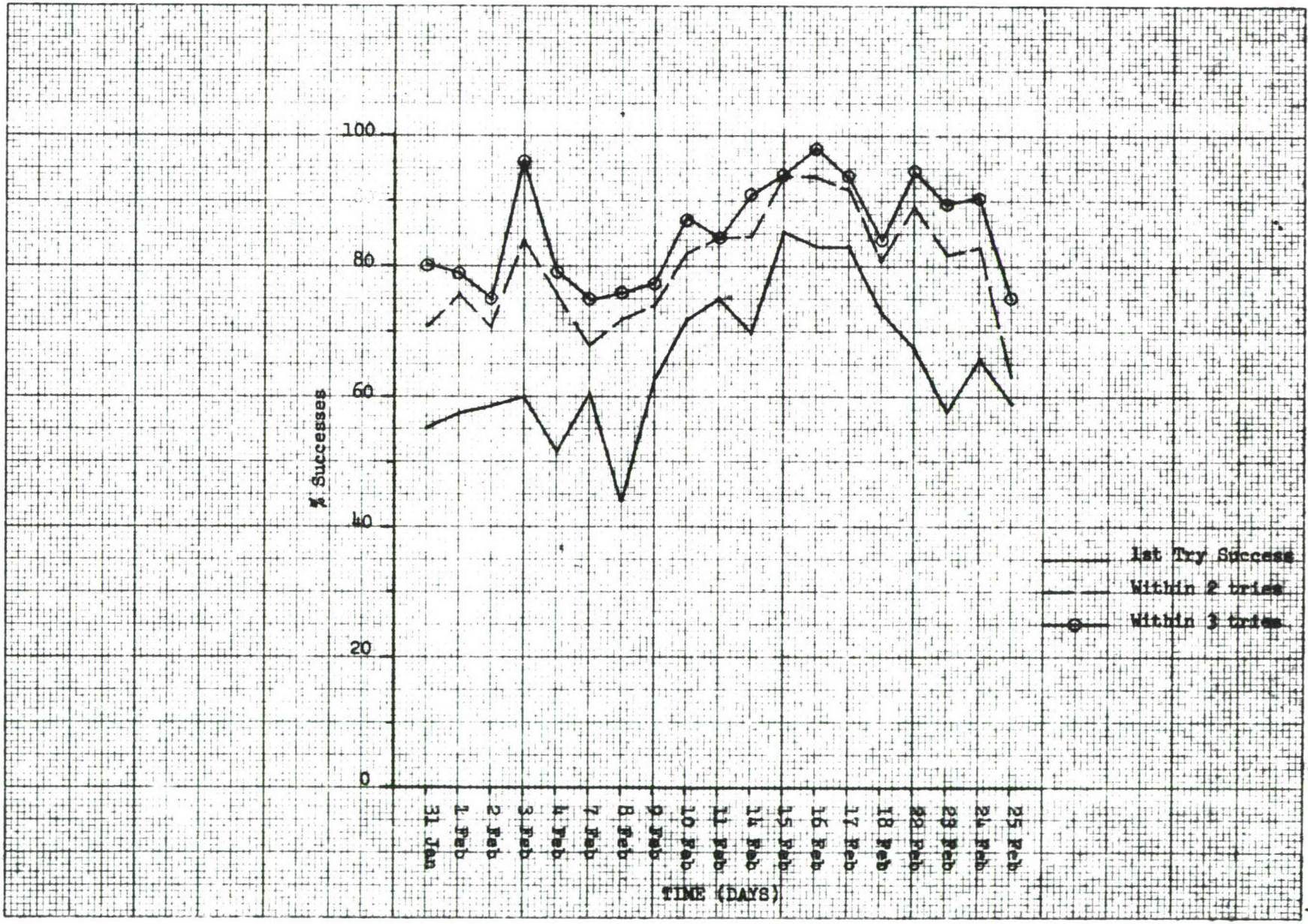

FIGURE 3: True Correlation Success Rate, Unit 1

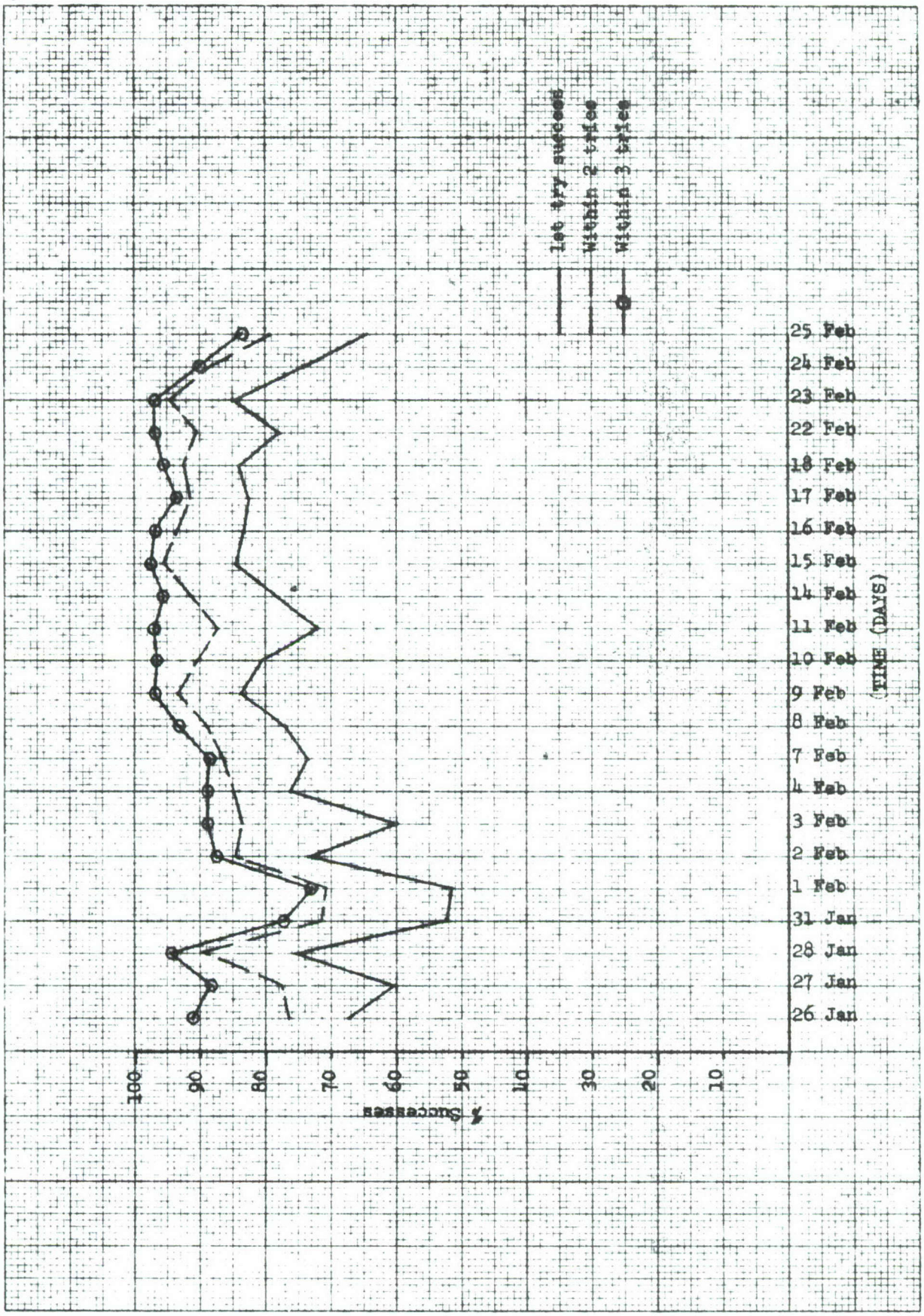

FIGURE 4: True Correlation Success Rate, Unit 2

indicates the percentage of successes attained within three tries (1st, 2nd, and 3rd-try successes all combined).

It will be noted that the success trend, though erratic from day-to-day, is generally an upward one during the first two to three weeks. This is primarily a reflection of the learning process which involves placing the finger on an oil pad to coat it with a light layer of silicone oil and then depositing a fingerprint on a transparent film in the COFID unit for comparison with the identification card. Learning to apply the correct amount of oil to the finger and applying the correct amount of pressure while holding the finger at the proper angle when depositing the fingerprint involves more skills than might be expected. The COFID unit is quite sensitive to variations which can occur in this procedure. This learning process is consistent with the experience indicated in earlier evaluations of the system (see Final Technical Report ARPA Order No. 1287 dated 15 November 1971, Title: Coherent Optical Fingerprint Identification System (COFIDS).

A second factor which contributed to this increasing success trend is that throughout the test, but primarily during the early part, new identification cards were being prepared for those people who consistently obtained low correlation voltages. The manner in which the test results were recorded make it impossible to separate these factors.

As a result of the learning and re-carding effects, the ultimate capabilities of this system are indicated during the latter half of the test. In evaluating the results, the last two days of the test must be interpreted as non-representative for the following reason. Throughout the test there were a number of people who could not or chose not to participate on a regular basis. Consequently, many of these people never completed the learning (and re-carding) process. During the last two days of the test, a special effort was made to obtain full participation and many of these people then made regular appearances. As a result, the average success rate during the last two days was reduced from that of the preceding ten days.

The over-all true-correlation results averaged over both the full test period and the last two weeks of the test are summarized in Table II below. In addition to showing numerically the improvement in performance during the last two weeks of test compared with the over-all test, Table II makes clear a fact not so obvious in Figures 3 and 4. The difference in results between the two COFID units is greater than the difference in the two test periods for either unit.

TABLE II

Average Results - True-Correlation Test
(% of Successful Appearances)

	COFID Unit 1		COFID Unit 2	
	Full Test Period	Last Two Weeks	Full Test Period	Last Two Weeks
First try	65.5%	71.8%	73.6%	79.5%
Within two tries	80.4	85.4	87.1	91.2
Within three tries	86.0	90.4	92.3	94.8

Two possible explanations could account for the differences between units:

a. A large fraction of the people using COFID Unit 1 were shop personnel (machine operators, model makers, etc.) who would tend to have less distinct fingerprints than others and whose fingerprints would be more subject to change from abuse. Most of the people using COFID Unit 2 were white-collar employees (engineering, administrative and clerical).

b. There could have been differences in sensitivity and adjustment between the two COFID units. Since preparation of the COFID units involves a large number of optical and electrical adjustments (so that they will operate with identification cards produced with a given master COFID unit), slight differences in performance are unavoidable. In addition, there are some uncontrolled variables (such as laser beam intensity, photocell response, and amplifier characteristics) which affect sensitivity and noise levels and cause some uncorrectable differences. The effects of these differences are discussed in succeeding sections of the report.

3. True-Correlation Statistics

Additional insight into COFID unit performance characteristics and differences can be gained by analyzing the statistics of correlation voltages measured throughout the test. It will be recalled from the Description of Equipment given above that the threshold-voltage setting determines the degree of correlation between fingerprint and ID card required for positive identification (true correlation). Based upon their experience with the equipment, the manufacturer recommended a threshold setting of 4 volts, and this was employed in the test. Consequently, verification of a fingerprint-ID card match was obtained only when the correlation voltage exceeded 4 volts.

Throughout the test program, recordings were made of all correlation voltages generated by fingerprint-ID card comparisons. The frequency distributions of these voltages for each of the two COFID units are shown in Figures 5 through 10. Figures 5 and 6 are the distributions for the complete test. Figures 7 and 8 are the distributions for the first half of the test. Figures 9 and 10 are the distributions for the last half of the test.

It will be noted in Figures 5 and 6 that the voltages are not normally distributed; they are multimodal (multi-humped) for both COFID units. The voltage distribution of Unit 1 (Figure 3) has not only a major central mode, but modes also at both the lower and upper ends of the distribution. Voltages for Unit 2 (Figure 6) are much more normally distributed and, surprisingly, show no upper mode. Although the means of the distributions are quite close (5.6 and 6.0 volts for Units 1 and 2, respectively), the large central modes are different by about 2.5 volts. This suggests that the average sensitivity of Unit 1 was lower than that of Unit 2. Some possible explanations for the high frequency with which low voltages (below 3 volts) occur are as follows:

a. The learning process during the first two weeks contributed significantly to the number of low-voltage readings. This appears to be confirmed by a comparison of the first-half test results (Figures 7 & 8) with the second-half test results (Figures 9 & 10).

b. The process of applying fingerprints is affected by the amount of oil on the oil-pad. Too little causes weak prints; too much causes smearing. Both situations occurred on more than one occasion during the test. In either event, a low correlation voltage results.

c. Some people had marginal ID cards for various periods of the test. The distribution of correlation voltages with these cards would be shifted toward the low-voltage end of the distributions shown in Figures 5 through 10.

d. Because of the lack of an award/penalty environment referred to under Test Procedure above, some participants were occasionally careless in performing the identification procedure.

Very likely, all of these factors (and probably others) contributed to the population of low-correlation voltages. In each of Figures 5 through 10 the percentage of voltages above 4 volts (the threshold value) is given. These indicate the percentages of true correlations for all attempts, whether or not they occurred at the same appearance of the participants (in contrast to the method of presenting the results in Section 2 above). Consequently, all of the low voltages (below 4 volts) would represent non-verifications. The frequency with which they occur provides a measure of the need for multiple attempts at verification.

The reason for the high-voltage mode associated only with Unit 1 is not obvious. It may be conjectured that this result reflects a fortuitous matching of fingerprint and ID card for a few of the people associated with

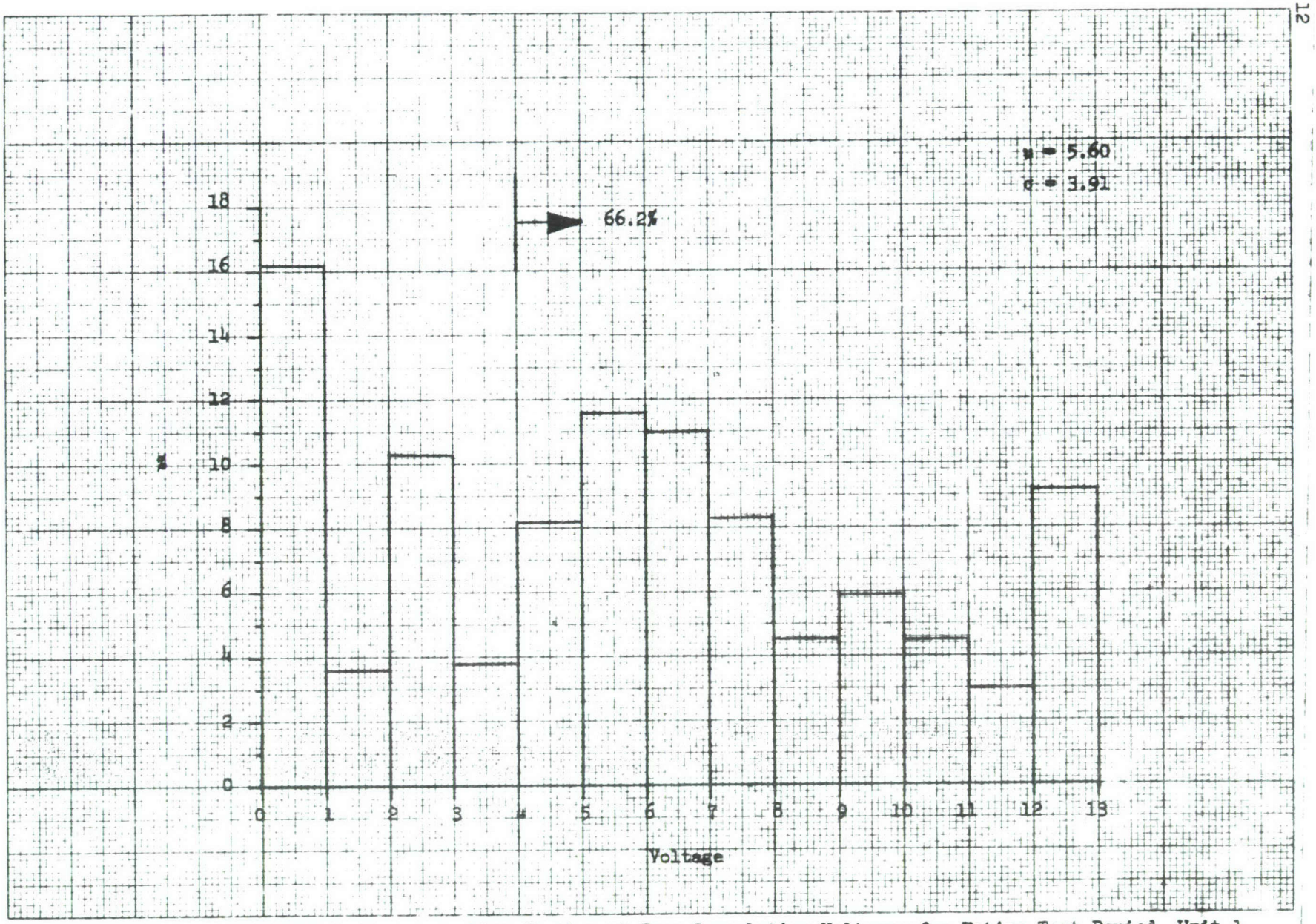

FIGURE 5: Frequency Distribution of True Correlation Voltages for Entire Test Period, Unit 1

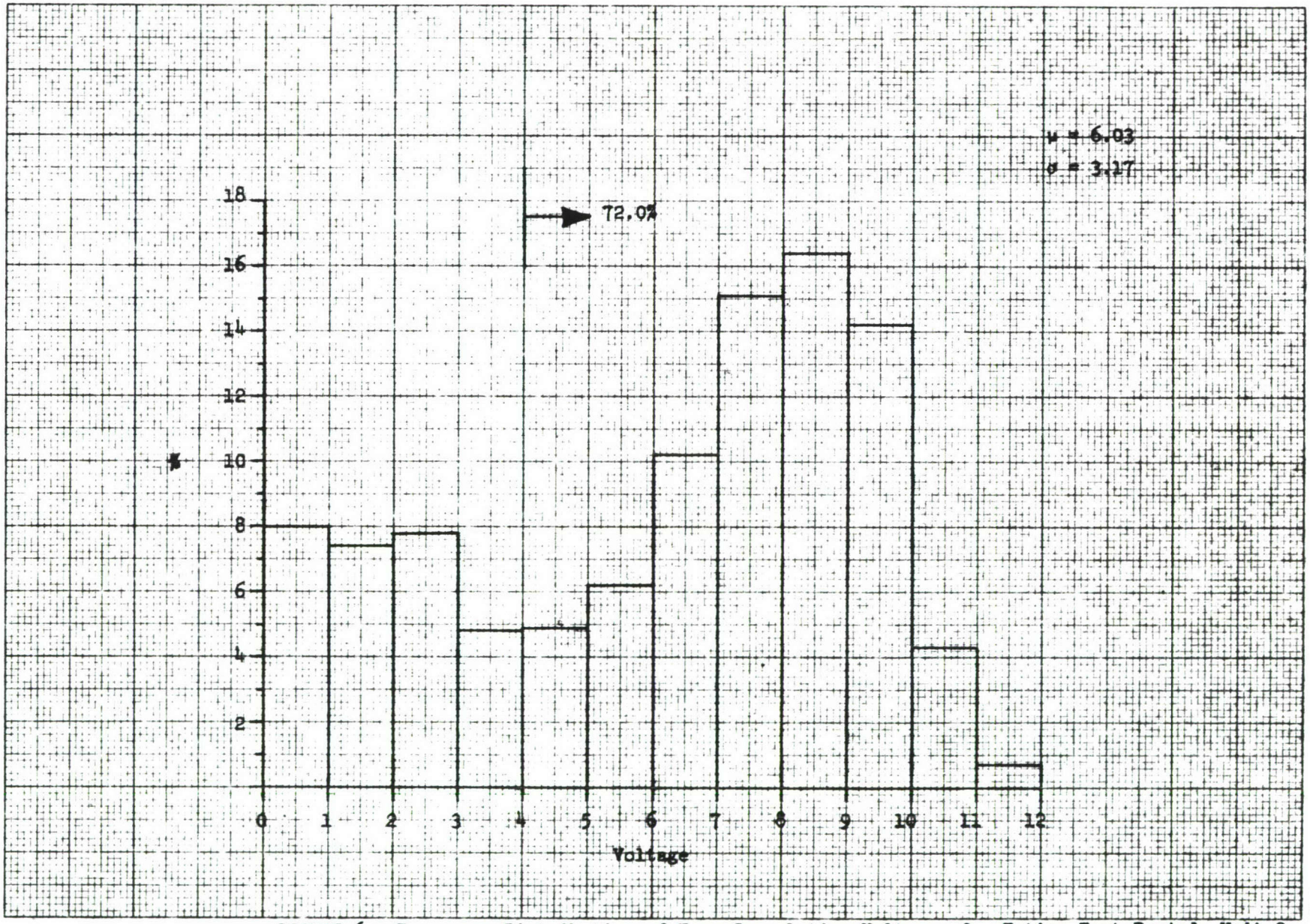

FIGURE 6: Frequency Distribution of True Correlation Voltages for Entire Test Period, Unit 2

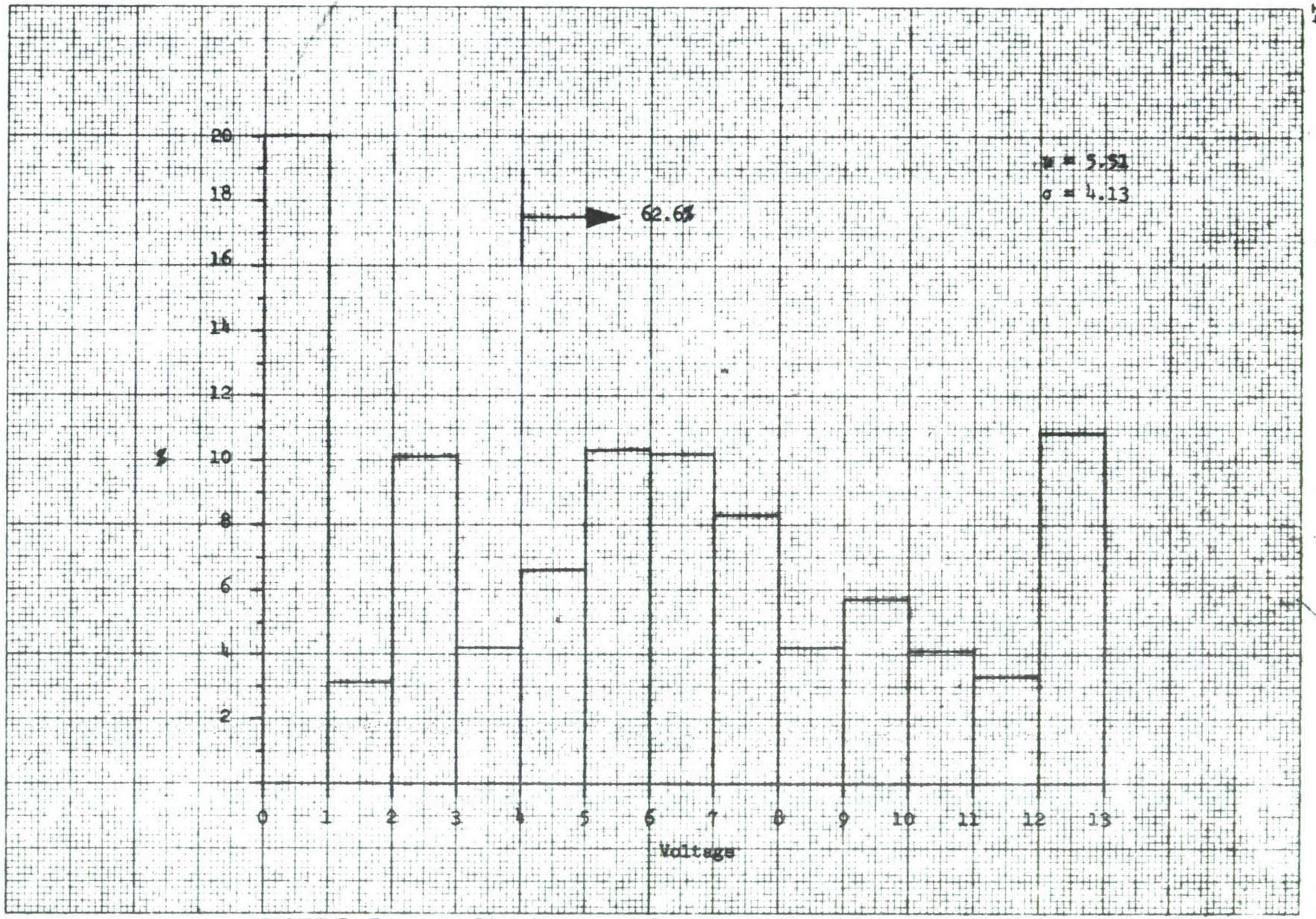

FIGURE 7: Frequency Distribution of True Correlation Voltages for 1st Half of Test, Unit 1

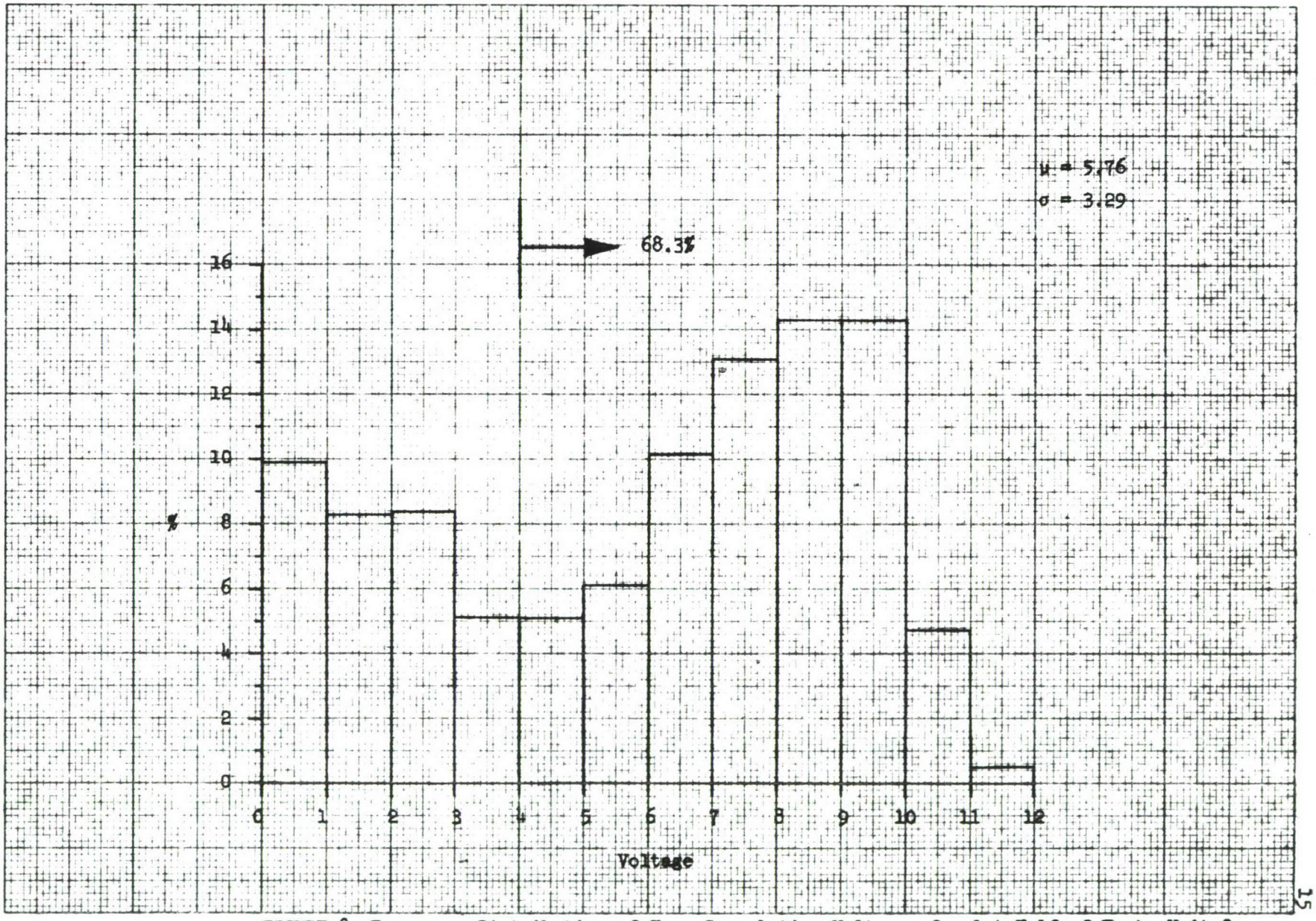

FIGURE 8: Frequency Distribution of True Correlation Voltages for 1st Half of Test, Unit 2

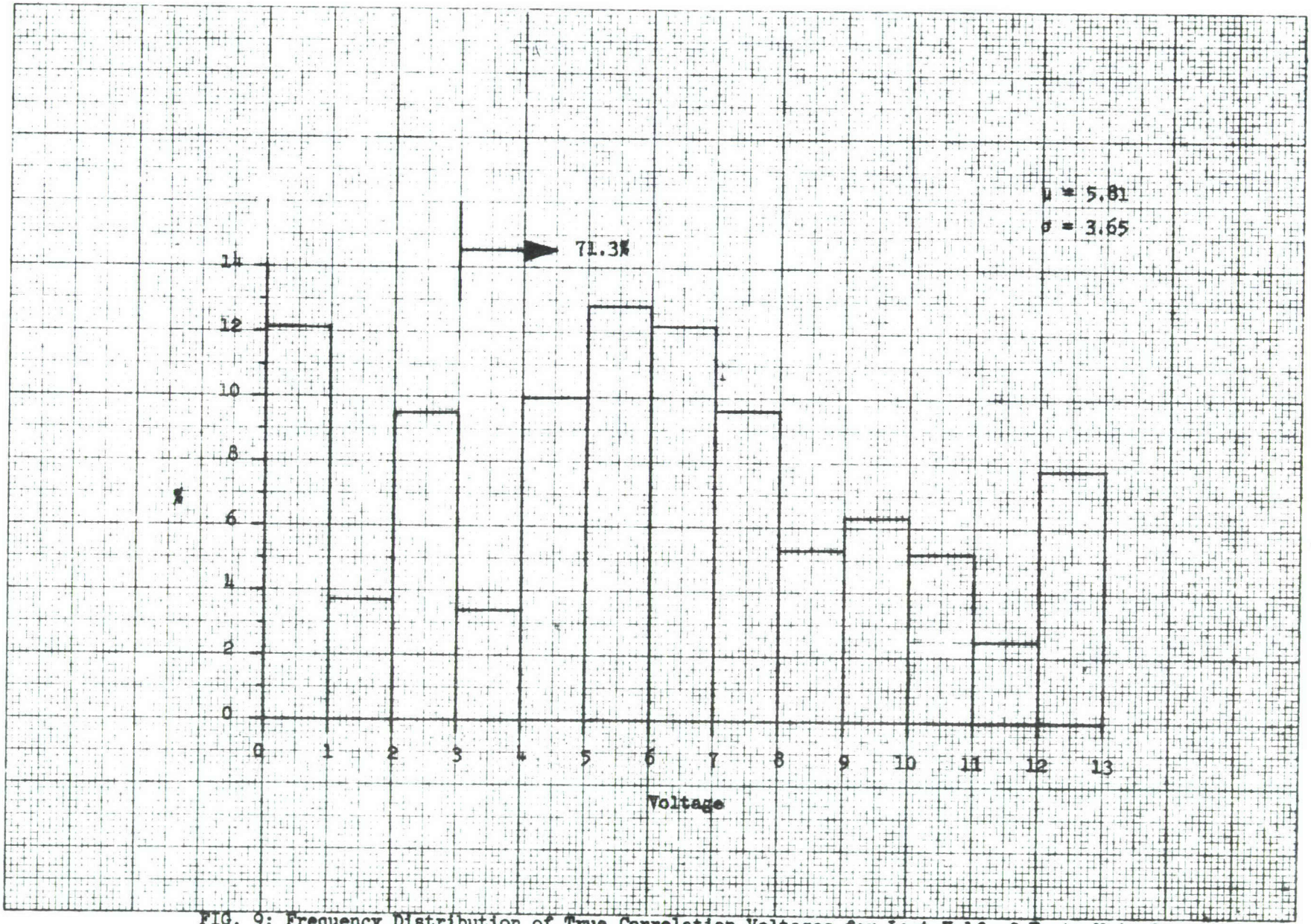

FIG. 9: Frequency Distribution of True Correlation Voltages for Last Half of Test, Unit 2
(Excluding last 2 days)

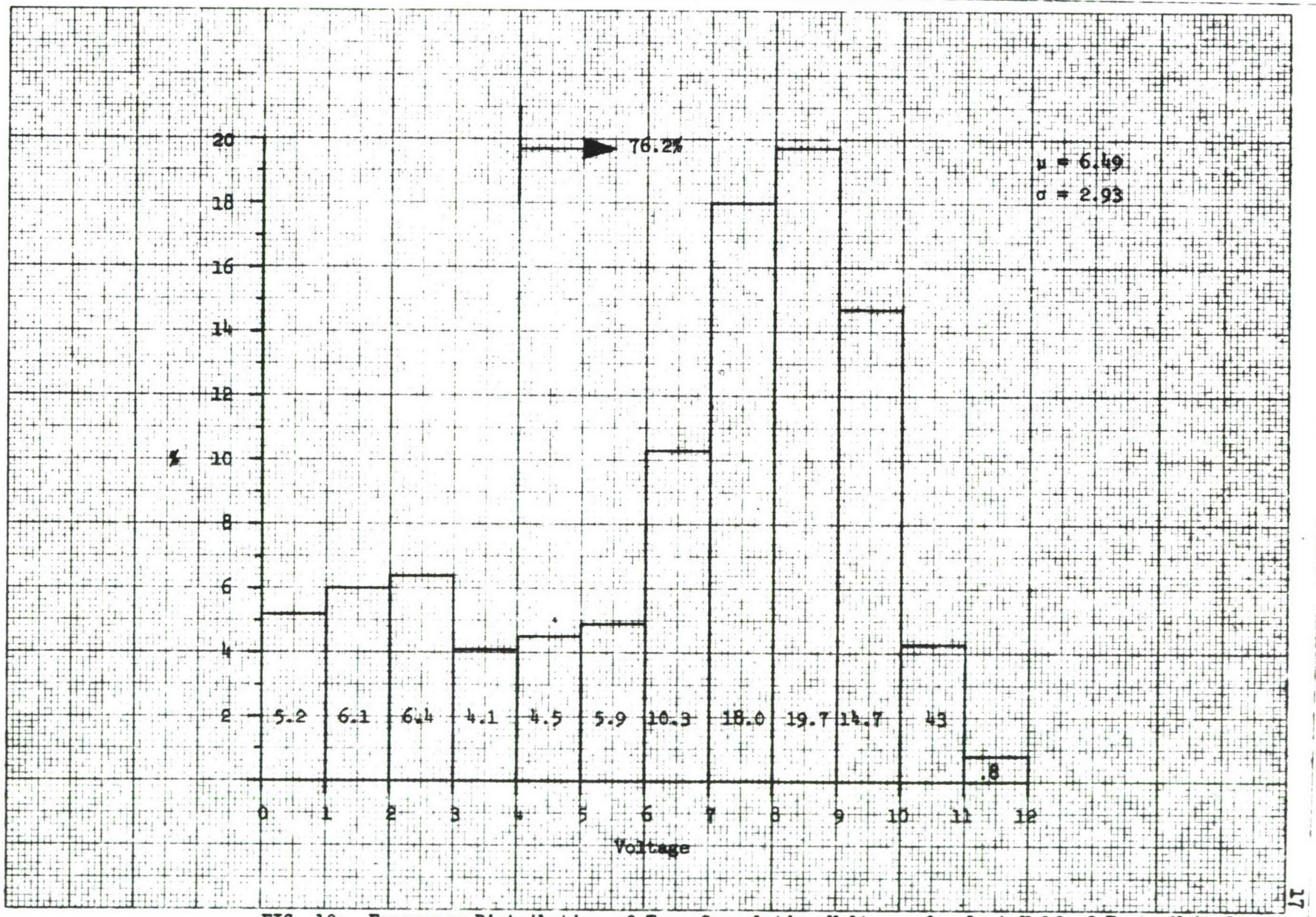

FIG. 10: Frequency Distribution of True Correlation Voltages for Last Half of Test, Unit 2 (Excluding last 2 days)

Unit 1. In any case, this effect is not deleterious to performance, as is the low-voltage mode, unless extreme cases occur. Cases of extremely high correlation voltages appear to have a slightly greater-than-average tendency toward false correlation. This tendency occurred for one participant in the present test and had been experienced in tests by the manufacturer. However, it is an easily resolved problem because "less-than-optimum" ID cards can always be produced for those people. The probability of such cards being produced illegitimately would appear to be extremely low.

4. False-Correlation Tests

For the purposes of this test, false correlation is said to occur whenever a verification of identity is given by the COFID unit with a fingerprint and identification card from two different people. Rate of occurrence of false correlations provides a measure of the differences in fingerprints among people and the discriminating capability of the COFID system. The over-all test results for false correlation are given in Table III:

TABLE III

FALSE-CORRELATION TEST RESULTS

	COFID UNIT 1	COFID UNIT 2
Number of False Correlations	0	4
Number of Attempts	662	2,297
Rate	.0000	.0017

False-correlation voltages were recorded throughout the test. Because of system noise levels, false-correlation voltages less than 0.5 volts could not be resolved and were assumed to be zero in the analysis. For COFID Unit 1 there were no voltages greater than 0.5 volts. For Unit 2 there were 87 out of the 2,297 attempts which provided false correlation voltages greater than 0.5, (i.e., 83 between 0.5 and 4.0 volts and 4 above 4.0 volts). This apparent difference between COFID units is consistent with the difference in sensitivity noted in the true-correlation data analysis above (Section 3). However, the data do not provide an adequate basis for reaching any firm conclusion in this regard.

The distribution of false-correlation voltages for COFID Unit 2 is shown in the histogram of Figure 11. It will be noted that the distribution is an approximately normal one (within the measurement limits), with a mean value of 0.054 volts. It is clear that the choice of 4 volts as a decision threshold was a reasonably good one since the probability of a false correlation occurring above this value is quite small (0.0017). Of course,

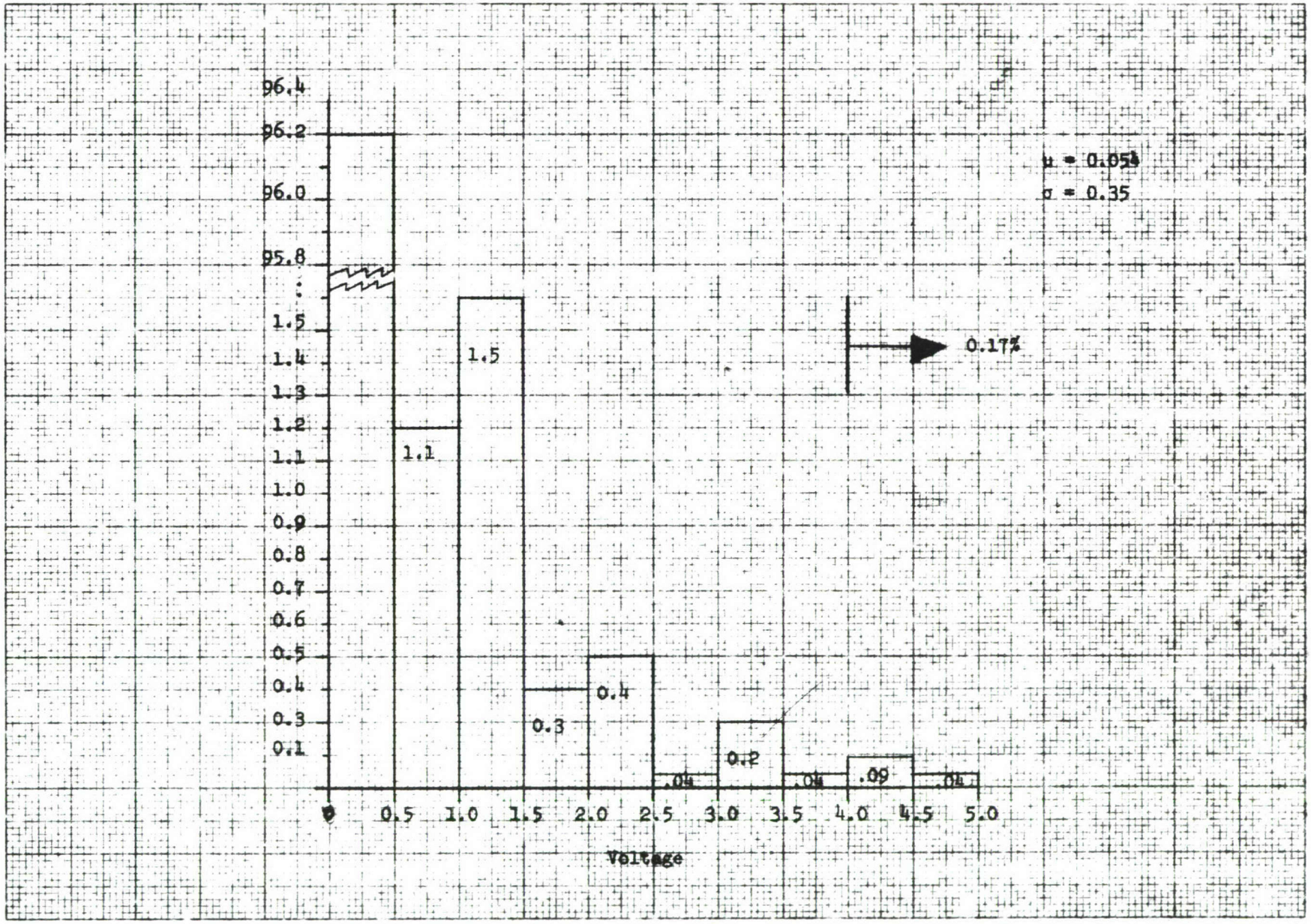

FIG. 11: Frequency Distribution of False Correlation Voltages for Full Test Period, Unit 2

the threshold voltage can readily be adjusted to higher values and thereby further reduce the probability of false correlation. The significance of such a choice is discussed in the following section.

5. System Trade-Offs

In normal use of the COFID system, three possible outcomes can occur:

a. True correlation is indicated - a person's fingerprint is verified against his ID card (a desirable outcome).

b. No correlation is indicated - no verification is obtained with a valid fingerprint-ID card combination (an undesirable outcome) or when a fingerprint is compared with the wrong card (a desirable outcome).

c. False Correlation - verification is obtained even though a fingerprint is compared with the wrong card (an undesirable outcome).

Some of the relationships which determine the likelihood of occurrence of these events are shown in Figure 12. This figure indicates the relationships among the false-correlation and true-correlation voltage distributions, and the threshold setting which existed during this test. The significant feature of this figure is that the two distributions overlap. If this did not exist, then the undesirable outcomes identified in b. and c. above would not occur. It would be possible to set the threshold voltage so that all true correlations were above threshold and all false correlations were below the threshold level. The overlap of distributions results primarily from the bi-modal, true-correlation distribution of COFID Unit 2 discussed in Section 3. Since some overlap of distributions appears unavoidable with the existing system design, there must always be some trade-off between false-correlation acceptance and true-correlation rejection.

The means for controlling this trade-off is by adjustment of the threshold-voltage setting and by establishing a maximum tolerable number of attempts to obtain verification. The relationships among these variables are described by Figure 13, which is based on the same data as Figure 12 (the performance of COFID Unit 2 during the last half of the test). The numbers along the curves are various possible threshold voltages. It is seen that increasing the threshold voltage lowers the percentage of successful verifications while lowering the false-correlation rate. Similarly, increasing the number of attempts increases both true and false correlation rates for a given threshold voltage. However, raising both the threshold voltage and the number of attempts in the "proper" manner will raise the percentage of successes while lowering the percentage of false correlations.

6. Equipment Reliability

Once the equipment had been adjusted and calibrated, it performed with a high degree of reliability throughout the test. The only difficulty resulted from the use of identification cards taken from different lots. One group of cards

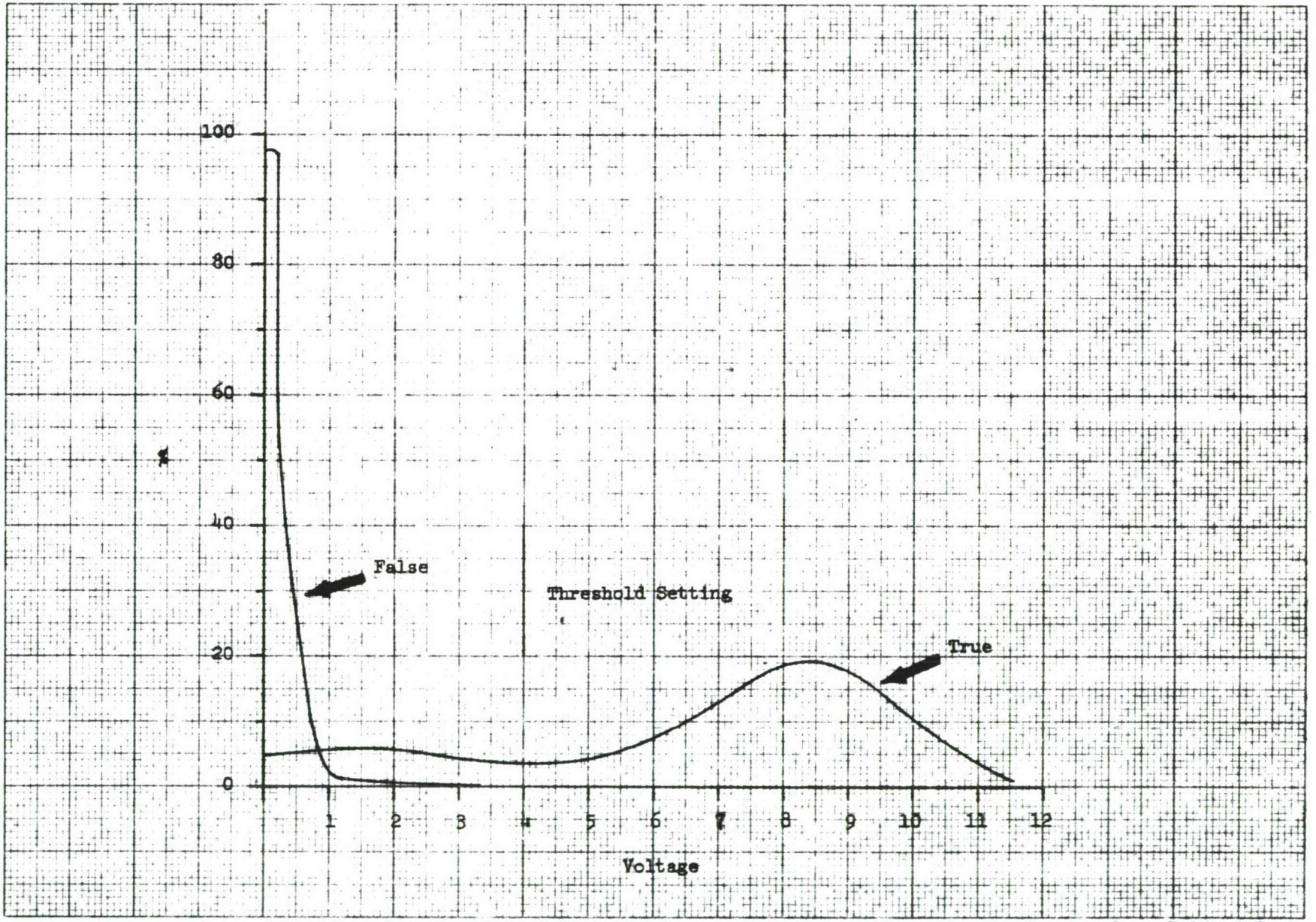

FIG. 12: False Correlation Distribution vs. True Correlation Distribution for Last Half of Test, Unit 2 (Excluding Last 2 Days)

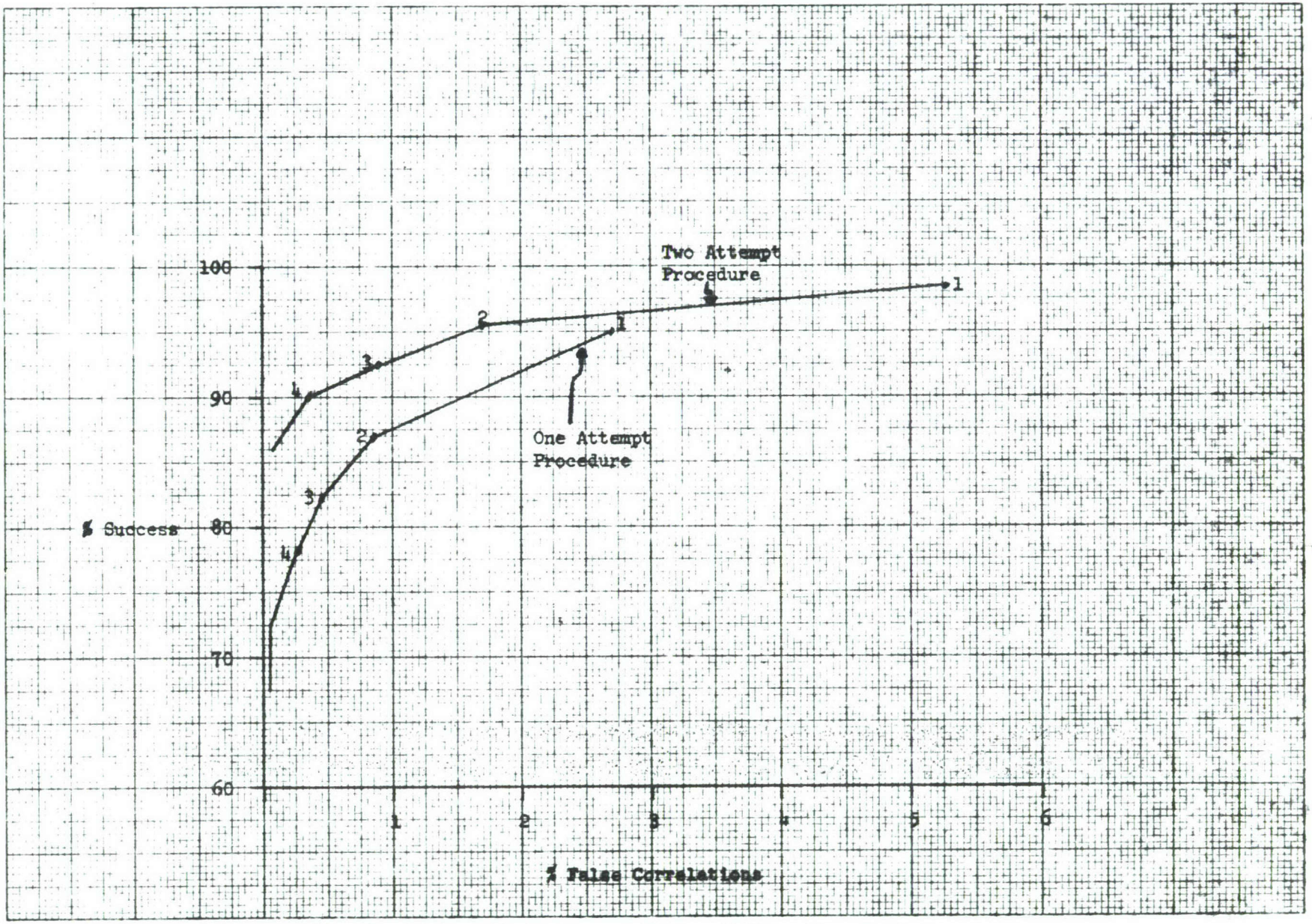

FIG. 13: Trade-Offs in Success Rate and False Correlations

was slightly smaller than the other. When one of the smaller cards was inserted in a COFID unit, it could become misaligned and would jam the mechanism. This required disassembly of several components and realignment of the COFID unit. The problem occurred a few times during the test. Otherwise, no repairs were necessary.

CONCLUSIONS

1. The COFID system provides a highly foolproof means of personnel identification which greatly reduces a basic weakness of most present methods: human error.

2. The COFID system is most suitable for applications involving small numbers of people because of its comparatively slow processing rate, approximately five seconds for each attempt at verification.

3. Although the test was too brief and the number of COFID units were too few to establish a failure rate, the units performed with high reliability throughout the test.

4. System performance can be improved by:

a. Incorporating a means for automatically adjusting system sensitivity to compensate for "weak" and very "strong" true-correlation signals. This could reduce the number of attempts necessary to obtain verification and would reduce the possibility of false correlation. (Since completion of the test, it has been learned that the manufacturer has incorporated automatic gain control in the electronic circuitry. This is in response to the problem implied by a. above. No data on the improved performance is available).

RECOMMENDATIONS

1. It is recommended that the COFID system be considered for use in applications where a high degree of access control is required.

2. Further development should be undertaken to improve the fingerprint deposition process. Specifically, methods for eliminating the deficiencies of the existing oil-pad technique should be investigated.

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